

The Observable of Lambda Polarity Caused by Source Global Angular Momentum Localizing in Peripheral Au-Au Collision at RHIC

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An observable to measure the polarity of lambda that caused by source global angular momentum in peripheral AU-AU collision at RHIC is proposed. This observable's capacity of measurement is tested by Monte Carlo method. And the main factors that influence the observable are also researched. This observable will give an effective proof of the formation of deconfined matter.

PACS numbers: 25.75.Nq, 25.75.Dw

I. INTRODUCTION

As we all know, only a few of events are center-to-center in Au-Au collision in RHIC because the nucleus has enough volume to be regarded as a ball rather than a point. Most of events are peripheral that is only a part of the nuclei collide to each other when two nuclei meet. Just as two macroscopical bodies collide peripherally to each other, a global angular momentum will be reserved in the overlapped region in heavy ion collision. It was firstly proposed by Liang and Wang [1, 2]. At the same time the unoverlapped parts keep on moving in initial direction and the overlapped part i.e. the source becomes still for the loss of momentum. The questions in front of us is how to verify the existence of the global angular momentum and how to measure it in experiment if it exists.

Unfortunately, the first question can not be replied directly because all information about the source we can get is from the final-state particles. On the other hand, many results from both experiment and theory show that a deconfined matter created after the collision. The first evidence comes from "jet quenching" [3, 4]. It was predicted to occur as a result of energy loss by the hard scattered partons due to interactions with the surrounding dense medium [5, 6, 7]. The theory of this energy loss has been a topic of intense research over the past few years [8, 9, 10, 11, 12][24]. The second evidence is the elliptic flow found in heavy ion collision. Quark coalescence model [19][20] has been applied to describe the elliptic flow at RHIC for different flavors [21, 22, 23][26]. Another surprising early measurements from RHIC shows that the proton/pion ratio reaches or even exceeds unity for transverse momenta p_t above 2 GeV/c [13]. One explanation for this phenomena is that quarks originating from different nucleon-nucleon collisions recombine via coalescence mechanisms [14, 15, 16, 17, 18][25]. If a matter composed by partons created in heavy ion collision, the global angular momentum between partons can convert to spin of final-state particles during the formation of these particles [1, 2]. The reason is that the orbital angular momentum of partons is part of spin of particle. So if the source has global angular momentum, this angular momentum will localize to final-state particles and the particles will be polarized. But if the matter is still confined, the polarization will not happens.

As experimental result supports the formation of deconfined matter, we go to the second question. Now the second question converts to how to measure the polarity of some kind of particle. This question will mainly be discussed in this paper: 1, choosing particle and observable; 2, arguing the relation between the observable and polarity; 3, factors influencing the measurement.

II. CHOOSING PARTICLE AND OBSERVABLE

There are some criterions in choosing the particle to reflect the global angular momentum of the source. Firstly, its spin can't be zero and its decay-length must be suitable to reconstruct. Secondly, it must decay by weak interaction and its daughter's angular distribution must be spherical asymmetrical because of the break-out of the conservation of parity in weak interaction. Finally, there must be many such particles produced in heavy ion collision so the mass of the particle should not too large. Under these criterions, $\Lambda/\bar{\Lambda}$ is a good candidate [1, 2].

After the particle is chosen the observable of the particle should be designed subsequently. We define a reaction plane in heavy ion collision by the beam direction and the impact parameter vector and we can fix it in experiment, but we can't distinguish which direction is up or down for the polarized particles if they are indeed polarized by the global angular momentum of the source. The distribution of the daughter of Λ (i.e. π^- and proton) is written as

$$P(\theta) = \frac{dN}{d\cos\theta} = \frac{1}{2}(1 + \alpha P_\Lambda \cos\theta) \quad (1)$$

θ is the polar angle in the center of mass frame of polarized Λ when we define the spin direction of Λ as the z axis. α is a constant for Λ decay and it equals 0.642. P_Λ is the polarizability of Λ . If all the event after turned to reaction plane are counted we will still get a symmetrical distribution of daughters of Λ in the center of mass frame of Λ because the second term of right of (1) will give a negative sign if the change of polar angle θ is π . To overcome this difficult, we define observable as following.

Firstly we should fix the reaction plane in experiment for an event. The reaction plane divide the x-y plane into two parts. We call one of them up direction and the other down direction. The reaction is immovable for the event and the Λ in it. For the event of $N\Lambda$ s we can count the number of Λ s whose one of the daughters such as proton belongs to the up or down direction in the center of mass frame of Λ as N_\uparrow and N_\downarrow . It is easy to know $N = N_\uparrow + N_\downarrow$. We define $M_N(i)$ for the i-th event of $N\Lambda$ s as

$$M_N(i) = |N_\uparrow - N_\downarrow| \quad (2)$$

.Then we add $M_N(i)$ for all the events of $N\Lambda$ s together to get M_N . N_{event} is the number of all events of $N\Lambda$ s. We can get

$$P(N) = \frac{M_N}{N_{event}} \quad (3)$$

The $P(N)$ is the observable to reflect the global angular momentum for the event whose number of Λ is N .

The next question asked instantly is why and how $P(N)$ reflects the existence of the global angular momentum of the source (i.e. the polarity of Λ emitting from it). Qualitatively, if Λ emitting from the source is polarized and the reaction plane has been confirmed, the numbers of Λ that crosses two sides of the reaction plane are unequal because of (1). The difference between them is $M_N(i)$ for the i -th event of $N\Lambda$ s. So it is obvious the relation between $P(N)$ and the polarization because of the relation between $P(N)$ and $M_N(i)$. Concretely, we calculate the value of $P(N)$ for the unpolarized event firstly, then contrast the value from real data to it.

III. THE RELATION BETWEEN THE OBSERVABLE AND POLARITY

To explain this issue, the first value should be calculated is the $P(N)$ for the unpolarized event. In unpolarized event, the spin direction of Λ is random. So it is easy to get:

$$P(N) = \frac{\sum_{m=0}^{m=N} |2m - n| C_n^m}{\sum_{m=0}^{m=N} C_n^m} \quad (4)$$

The value of $P(N)$ is listed below: (calculated from Λ). The

N	2	3	4	5	6	7	8
P(N)	1	1.5	1.5	1.875	1.875	2.1875	2.1875

FIG. 1: The value of $P(N)$ in unpolarized event

probability of there are m Λ whose proton belong to up direction of the reaction plane is $\frac{C_n^m}{\sum_{m=0}^n C_n^m} \cdot |N_{\uparrow} - N_{\downarrow}|$ is $|m - (n - m)|$ i.e. $|2m - n|$ for event of $N\Lambda$. Add the probability multiplied by $|2m - n|$ for m from 0 to N and the expression of $P(N)$ can be got as (4).

Calculating the value of $P(N)$ in unpolarized event, we should estimate the $P(N)$ and the variance of it in polarized event for the statistical quantity that we can get from experiment. We can do that just like we define $P(N)$ by use of Monte Carlo. After selecting the events that contain $N\Lambda$ s and turning to the center of mass frame of each Λ , we produce direction of proton from Λ satisfying the distribution of (1) regarding x axis as the reaction plane for all events. Then count the number of protons that lies in the first and second quadrants as N_{\uparrow} and that in the third and fourth quadrants as N_{\downarrow} . After counting and adding the difference of these two value (i.e. $M_N(i)$) for all event of $N\Lambda$ s, we can get $P(N)$ by use of (3). This process should be repeated for many times for example 50 times to get the variance of $P(N)$. The pictures below show the result

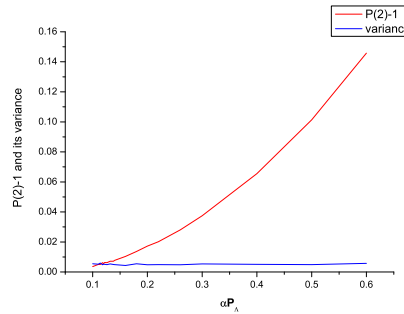


FIG. 2: Monte Carlo result for $N=2$, the red line is $P(2)-1$, the blue line is the variance of $P(2)$ for 50 times

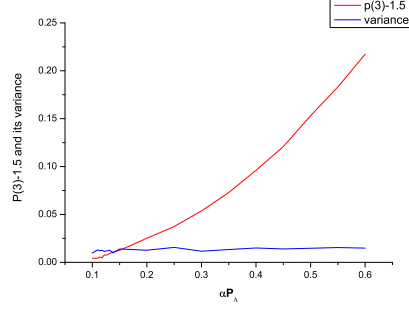


FIG. 3: Monte Carlo result for $N=3$, the red line is $P(3)-1.5$, the blue line is the variance of $P(3)$ for 50 times

The accuracy of this method is determined by the ratio of $P(N) - P_r(N)$ to the variance of $P(N)$. $P_r(N)$ means the reference value for $P(N)$ in unpolarized events listed in Fig.1. Presumably if the degree of confidence is set to 3σ , we can get signal in case of $\alpha P_\Lambda > 0.2$. This estimate is from Fig.2 and Fig.3 with no other factors considered.

IV. FACTORS INFLUENCING THE MEASUREMENT

The value of $P(N)$ is affected by a lot of factors. We will discuss the main ones in this section. Obviously, the resolution of reaction plane can influence $P(N)$ severely. If the real reaction plane is known, the degree of asymmetry between up and down the reaction plane is the maximum of whatever resolution of reaction plane. On the other hand, if the resolution of reaction plane is π , in other words, we don't know the reaction plane, the value of $P(N)$ will equal that in unpolarized events. Picture below gives the trend of $P(2)$ at $\alpha P_\Lambda = 0.2$.

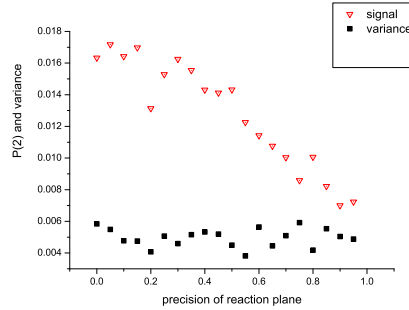


FIG. 4: Monte Carlo result for $N=2$, the red triangle is $P(2)-1$, the black square is the variance of it for 50 times, X-axis means the reaction plane resolution divided by π

From Fig.4 we can know that if this method is feasible at $N=2$ and $\alpha P_\Lambda = 0.2$ the resolution of reaction plane must be smaller than 0.4π . This is a quite loose requirement.

Another factor is the resolution of momentum. The direction of proton decayed from Λ is measured in the center of mass frame and the transformation from laboratory frame to the center of mass frame needs the momentum of both proton and pion decayed from Λ . So the resolution of momentum will affect the direction of daughters of Λ . The picture below shows the trend of $P(2)$ depending on the momentum resolution at $\alpha P_\Lambda = 0.2$. From Fig.5 we can know that the variety of $P(2)$ depending on the momentum resolution from 0 to 20 MeV is un conspicuous. So the influence from momentum resolution should be small.

There are also other factors that affect $P(N)$, such as the purity of Λ . We can estimate the influence of it from the reconstruction of Λ .

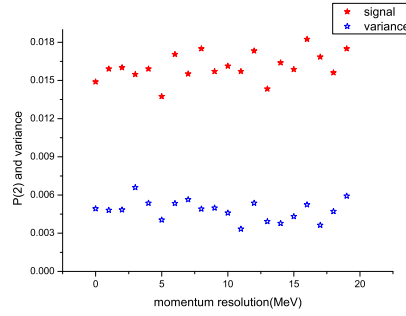


FIG. 5: Monte Carlo result for $N=2$, the red pentacle is $P(2)-1$, the blue empty pentacle is the variance of it for 50 times, X-axis means the momentum resolution

V. CONCLUSIONS

An observable $P(N)$ to measure the source global angular momentum localization in peripheral AU-AU collision at RHIC is proposed in this article. And the relation between $P(N)$ and the polarizability is shown by simulation in which the quantity of statistics is from real data of AU-AU collision in 200 GeV at STAR in 2001. The variance of $P(N)$ is also shown by this. Then the factors that can influence $P(N)$ are discussed. The influence of momentum resolution is trivial within the resolution of STAR detector. From simulation result, the resolution of reaction plane should be smaller than 0.4π for a feasible measurement. If αP_Λ is bigger than 0.2 i.e. $P_\Lambda > 0.312$, this method can give a meaningful result with the degree of confidence about 3σ . If αP_Λ is smaller than 0.2, this method can give an upper limit of P_Λ .

Acknowledgments: We thank Dr J. Fu for supporting us in many respects and their constant helps. We thank Prof. J. Li and Z. Zhang for the earnest supervision. We thank Prof. Shaomin Chen and Yuaning Gao for the fruitful discussions in this work. The work was supported in part by the grants NSFC 10447123.

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